

Visible interferometric coupling of two telescopes through single mode optical fibers

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Abstract

The diameter of large conventional astronomical telescopes is currently restricted to the range of eight to ten meters. With this limitation in mind, there is an emerging interest in various applications of optical interferometry which would allow the synthesis of apertures larger than can be realized using current mirror fabrication technologies. Interferometry allows the substitution of the separation between telescopes to determine the limiting resolution rather than the diffraction limited resolving power of the individual telescope aperture(s). The implementation of this process, however, requires solutions to a number of difficult problems in the transport and recombination of optical wavefronts. The use of single mode (SM) optical fibers to transport and recombine optical wavefronts in interferometers offers a number of advantages as compared to other, more established techniques, yet suffers from an inefficient coupling of the wavefront energy into the very narrow fiber cores. We present preliminary results of an experiment in which interferometric recombination of wavefronts from two telescopes using SM fibers was used to obtain white light fringes on the bright star Arcturus (α Bootis). Our experience leads us to believe that for many imaging applications the continued development of fiber based interferometry will yield significant resolution gains over the diffraction limited performance associated with conventional monolithic aperture systems.

Keywords: Optical fibers; Interferometry; Astronomical imaging

1. Introduction

The use of SM fibers to transport optical wavefronts in Michelson interferometers has been suggested by a few authors [1,2]. Characteristics of SM fibers that make them attractive for interferometric beam transport and recombination are summarized below:

– *Spatial filtering:* SM fibers spatially filter most of the high frequency phase perturbations introduced into the wavefront by the turbulent atmosphere.

– *High level of coherence preservation:* The coherence of the spatially filtered wavefront is preserved as the light propagates through the fiber.

– *Almost lossless transport of energy:* Research and development within the communication industry has led to the development of SM fibers with extremely low power dissipation, thus allowing nearly lossless propagation of wavefront energy through long sections of fiber.

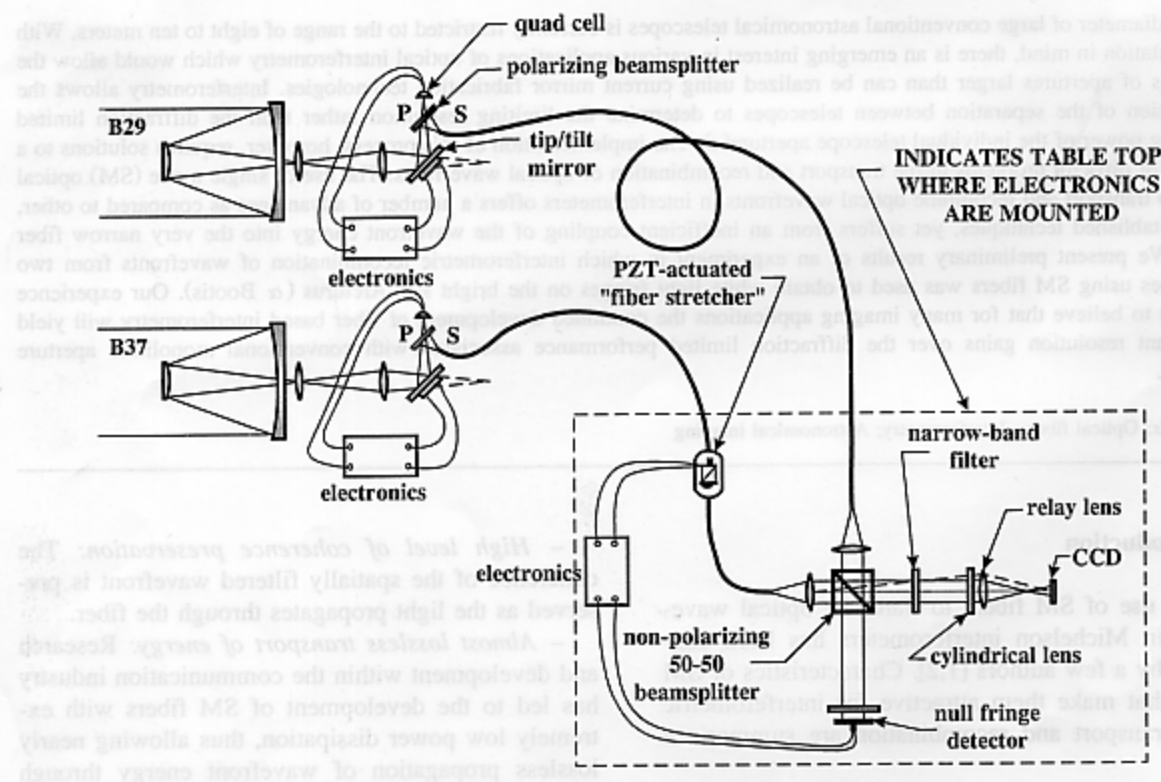
The principle impediment to the use of fibers in interferometry is their poor coupling efficiency, i.e.

the small fraction of wavefront energy that can be injected into the fiber cores. The primary cause of this loss has to do with the extremely small cross section of the core, the region of the fiber that carries the signal, being on the order of only a few microns in diameter, much smaller than a typical turbulence broadened stellar image. For this reason alone there have been few experimental efforts to evaluate fiber interferometer concepts on telescopes, especially at visible wavelengths where the effects of atmospheric turbulence are more severe than at longer wavelengths. A preliminary experiment, without beam stabilization or phase control servos, has been carried out in the near infra-red region recently by the authors of Ref. [3]. The experiment described in this paper addresses two of the fundamental issues involved in the use of SM fibers for optical interferometry. The first goal was to measure the signal power

coupling efficiency between telescope and fiber, both with and without compensation for image motion caused by atmospherically induced wavefront tip/tilt over the telescope's entrance pupil. The second goal was to use interferometric beam recombination to record a white light fringe using a star as a source. Both of these goals were achieved during two observing runs at the Air Force Maui Space Surveillance Station (MSSS) in Maui, Hawaii during the periods February 1995 and June 1995, respectively.

2. The experimental set-up

The Maui Space Surveillance Site was chosen as the site for the experiment due to the availability of a unique facility, the Maui Optical Tracking and Imaging Facility (MOTIF) telescope. The MOTIF consists



Schematic of the Experimental Lay-Out

Fig. 1. Optical lay-out of the experiment.

of two 1.2 m telescopes co-mounted in a “binocular” arrangement without a common optical path. The center to center separation of the two telescopes is 4 m. The main part of the Phillips Laboratory experiment consisted of two independent wavefront tip/tilt servo loop controllers [4] and wavefront coupling optics for each telescope. A second main controller was the strain-controller loop.

A schematic diagram of the optical lay-out is shown in Fig. 1. The tip/tilt controller, which is described in detail in Ref. 4, consists of a commercial quad-cell sensor using four voice-coil actuators as the tip/tilt mirror actuators. The maximum bandwidth achieved to date in closed loop operation is 500 Hz. The two telescopes have different f num-

bers requiring different re-imaging optics for each telescope in order to achieve the same numerical aperture on the fibers. The detector used to record the fringes was a commercial CCD camera with a Kodak chip having 768×512 pixels, of which 128×64 were actually used to record data.

The bright star α Bootis (Arcturus), visual magnitude -0.2 , was chosen as the stellar source for the experiment. A number of measurements of the wavefront power coupling efficiency were collected on one of the two telescopes, both with and without use of the wavefront tip/tilt corrector. With the tip/tilt corrector turned off an average coupling efficiency of 0.09% was measured using 50 frames of data while with the tip/tilt corrector operating an average

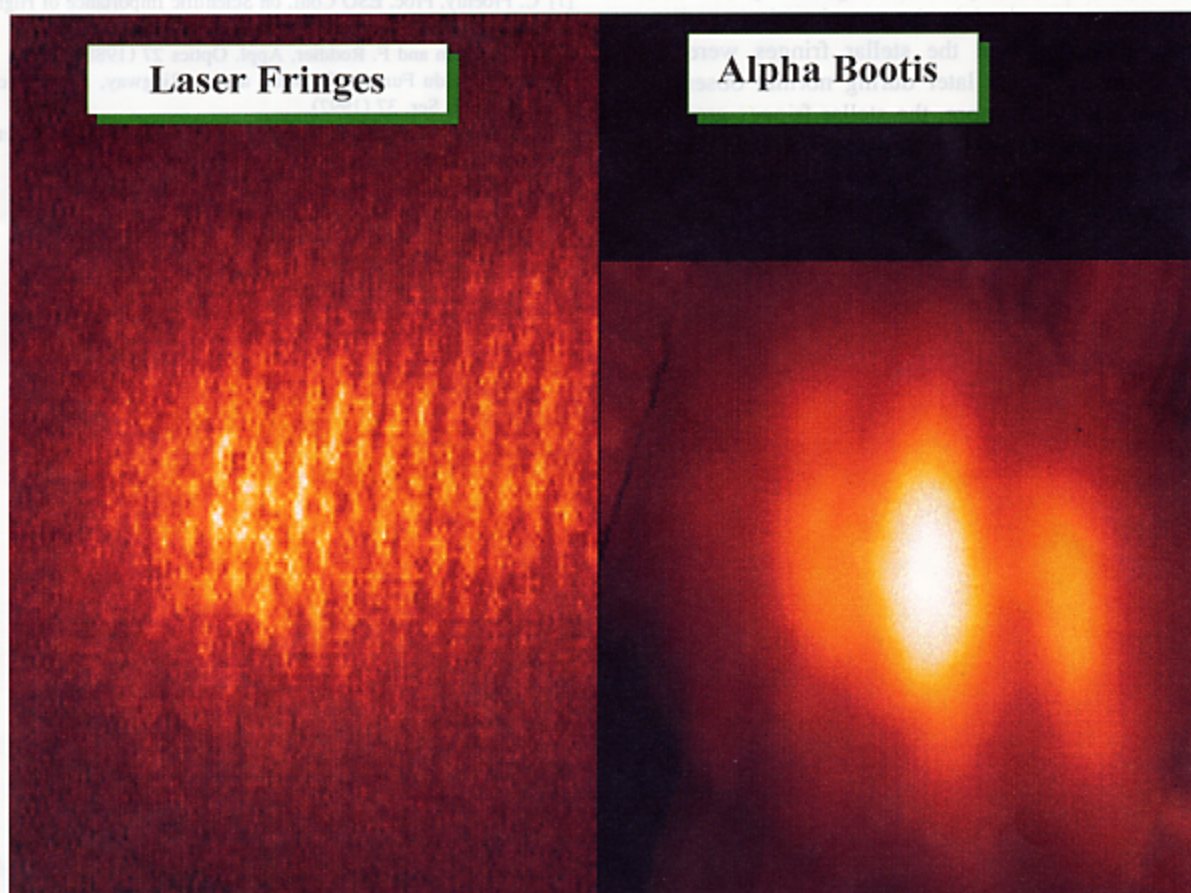


Fig. 2. Two sets of fringes obtained with the laser (during alignment) and with the star Alpha Bootis.

coupling efficiency of 3% was achieved. These results match closely the theoretical prediction given by the following expression [5],

$$\eta \approx \left(\frac{r_0}{D}\right)^2 \left[1 + 1.06\mu \left(\frac{r_0}{D}\right)^{1/3} + 1.24\mu^2 \left(\frac{r_0}{D}\right)^{2/3} \right]$$

where η is the maximum coupling efficiency, r_0 the coherence diameter of the atmosphere [6], D the diameter of the telescope, and μ a parameter equal to 1 or 0 depending on whether wavefront tip/tilt is removed or not. For this experiment D was 120 cm and r_0 approximately 10 cm. Fig. 2 shows side by side a frame of fringes obtained with the laser illuminating both telescopes and a frame of fringes obtained from the star. The average measured visibility of the fringes is 30%. Note that the spacing of the fringes changes due to an apparent motion of the recombination beam splitter during the day (the laser fringes were acquired in the morning during alignment procedures and the stellar fringes were acquired several hours later during normal observing operations). Furthermore, the stellar fringes are visible over a smaller field of view than the laser fringes due to the broad bandwidth of the interfered starlight (100 nm).

3. Conclusions

We have reported the first controlled interferometric link between two independent telescopes at visible wavelengths using SM fibers. Once this technology is fully exploited the use of single mode fibers may dramatically reduce the development cost of ground-based optical interferometers and has the potential for even larger savings with spaced-based systems. The development and use of optical interferometric arrays equivalent to such large radio interferometers as the Very large Array Radio Telescope will open completely new chapters in the fields of astronomy and very high resolution imaging.

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